Assessment of Groundwater Discharge to the Coastal Zone: Development of a Submarine Radon Monitor

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LONG-TERM GOALS

One of the persistent uncertainties in establishing marine geochemical mass balances is evaluating the influence of submarine groundwater discharge (SGD) into the ocean. Our long-term goal is to develop geochemical tools (i.e., radon and radium isotopes) to quantify the magnitude of SGD on a local to regional scale. Improvements in field-based analytical devises is sought in order to allow evaluations on more time efficient basis. Since there is no standard methodology for assessment of groundwater flow into the ocean, we are actively involved in coordinating and participating in method intercomparisons.

OBJECTIVES

Radon is a good natural tracer of SGD because its concentration is very high in groundwater but low in seawater, it behaves conservatively, and it is relatively easy to measure. Assessment of possible temporal trends of radon is important because submarine groundwater flow is known to be extremely variable — in some cases even reversing direction in response to external forcing (tides, change in water table height, etc.). Although ^{222}Rn in water may be measured reliably by classical collection methods and laboratory analysis via techniques such as radon emanation (Mathieu et al., 1988), the approach can provide information only about water bodies over limited areas and time periods. Our specific objectives for this research are: (1) to develop a continuous radon monitor; (2) to test this system in the field over several different time scales to evaluate short (tidal) to long-term (seasonal) patterns; (3) to develop a technique for quickly measuring ^{224}Ra ($t_{1/2}$ = 3.83 days) in the field; and (4) to test the radon and radium tracing approach over more conventional methods for evaluating groundwater discharge.

APPROACH

We investigated two approaches for a continuous radon monitor: (a) an "active" system which circulates water to an exchanger where radon is stripped, concentrated, and delivered to an atmospheric monitor for measurement; and (b) a "passive" monitor which relies on radon diffusion through a membrane to reach the detection system. We have determined that while the passive approach is sound in principle, the diffusion across the membrane is too slow for monitoring over time scales of hours or less. The active system, on the other hand, can provide concentration data with a

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14. ABSTRACT
One of the persistent uncertainties in establishing marine geochemical mass balances is evaluating the influence of submarine groundwater discharge (SGD) into the ocean. Our long-term goal is to develop geochemical tools (i.e., radon and radium isotopes) to quantify the magnitude of SGD on a local to regional scale. Improvements in field-based analytical devises is sought in order to allow evaluations on more time efficient basis. Since there is no standard methodology for assessment of groundwater flow into the ocean, we are actively involved in coordinating and participating in method intercomparisons.

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resolution dependent upon the amount of radon in the system (we have found that 1-2 hour integrations are usually suitable).

In order to evaluate the system and the models we use to interpret the radon results in terms of SGD, we are investigating different coastal systems together with a variety of other techniques (seepage meters, hydrological modeling, etc.). Those results are encouraging but have also shown that there is a discrepancy between the "total" flow, as measured by tracer and seepage meter techniques, and the "hydrological flow" as estimated by hydrogeological models. This is likely a consequence of using models that consider only measured onshore-to-offshore hydraulic gradients, as well as density-dependent circulation below the seabed. No attempts were made to include oceanic forces such as tidal pumping and wave action which may have been responsible for a good deal of the fluid exchange in the systems investigated thus far. Separating these components will be a major thrust of our continued research in this area.

WORK COMPLETED

For the active radon monitoring system, we constructed a water exchanger to distribute the radon in water into the air for measurement. The water-air exchanger is simply a clear plastic (acrylic) tube which has water flowing through it continuously with a provision for a stream of air which is pumped, either from the built-in air pump in a "RAD-7" radon monitor or an external pump, and re-circulated through a bed of desiccant and then to the RAD-7 for measurement (**Figure 1**). After some time, the radon concentration in the air reaches equilibrium with the radon in the water, the ratio at equilibrium being determined by the water temperature (Weigel, 1978). The data are stored in a data logger on-board the RAD-7 and easily downloaded to a PC for final analysis. The principles and preliminary evaluation of this system were recently published (Burnett et al., 2001).

Figure 1. Photograph of the continuous radon-in water monitor.
[The exchanger, upper left, mixes seawater from a submersible pump with a stream of air that is then routed to the radon monitor, lower right]

In addition, we developed a technique to measure ^{224}Ra and ^{226}Ra in seawater using the same radon-in-air monitor that is being used for the “active” radon-in-water monitor. Since Ra activities are very low in seawater, the radium is first quantitatively pre-concentrated onto MnO_2 coated acrylic fiber in a column mode. Then, the excess water is removed from the fiber to obtain optimum conditions for Rn recoil to the air. The Ra daughters (^{222}Rn, ^{220}Rn, and ^{219}Rn) in the column are circulated through a closed-air loop to the RAD-7 and analyzed. We evaluated this system by comparison to the delayed-coincidence counters (Moore and Arnold, 1996) and the results agreed very well. A paper describing this portable approach for analysis of radium isotopes was recently accepted for publication (Kim et al., 2001).

RESULTS

We organized an intercomparison experiment of different SGD evaluation approaches at a site near the FSU Marine Laboratory on the Gulf of Mexico during August 2000. We thus had the opportunity to evaluate groundwater discharge into a coastal zone by several independent techniques including seepage meters of different designs (manually-operated, heat-pulse technology, and ultrasonically based), hydrological modeling, and tracers. All three types of seepage meters showed generally excellent agreement when different types of meters were deployed side-by-side (**Fig. 2**). Seepage flux results showed that a strong periodicity is present with a wavelength of about 12 hours, strongly suggestive of a tidal influence. The peaks in the continuous seepage records tended to coincide with falling tides. Note the close agreement between the manually operated (“Lee-type”) seepage meter, and the two automated meters. The radon concentration increases shortly after the maximum in seepage and reaches a peak at the lowest tidal level.

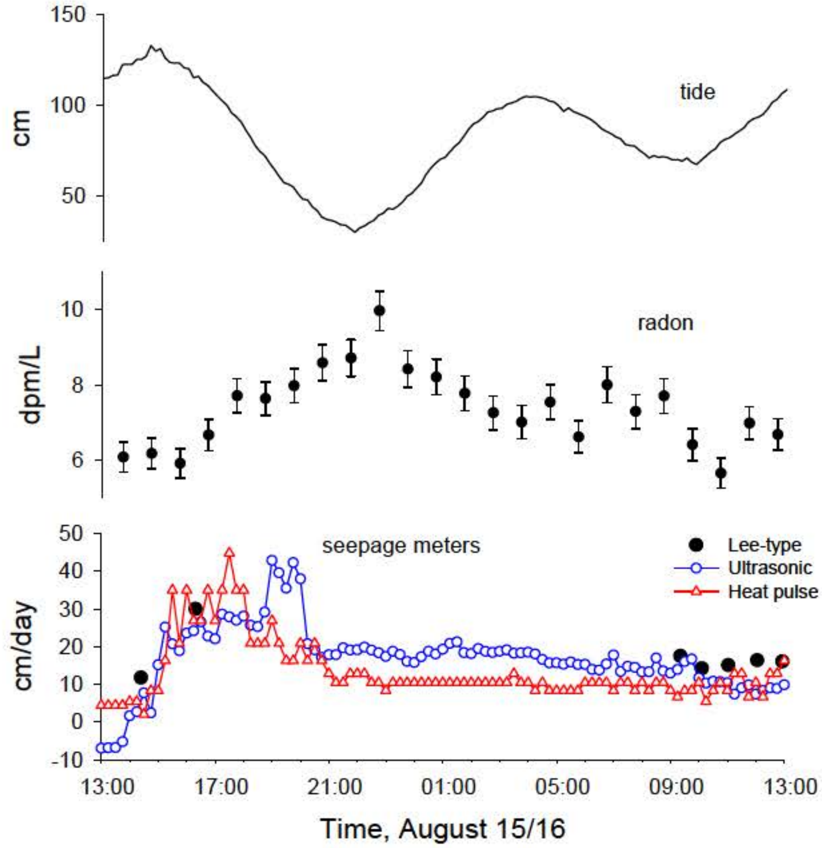

Figure 2. Time variation of measured parameters over one 24-hour period. [Plot shows trends in seepage rates, radon concentration, and tidal height at one location]

The continuous radon monitor was run throughout the entire experiment with an integration time of 1-hour. The water depth was also continuously monitored at the same location, so we were able to produce a record of total ^{222}Rn inventories over time. In addition, we made continuous measurements of wind speed, air and water temperature, and atmospheric radon during the same period. We corrected the measured ^{222}Rn inventories for ^{226}Ra-supported activities, for atmospheric losses of radon, and estimated mixing losses out to sea. The change in the corrected inventories per unit time provides estimates of the total flux into the system required to balance the observed radon. Once this radon flux information is established, we convert to a water flux by dividing the calculated fluxes by the concentration of ^{222}Rn in the sediment pore water. We estimated the relevant ^{222}Rn concentration within the interstitial fluids by performing sediment equilibration experiments. The results of these operations for each of our 1-hour time steps shows a pattern very much in line with that displayed by the automated seepage meters (**Fig. 3**). We then made total discharge estimates by scaling the calculated upwelling rate to the entire 20,000-m^2-study domain. We pooled these estimates (1.7-2.5 m^3/min) into 24-hour time periods to allow direct comparison to the integrated daily seepage meter results.

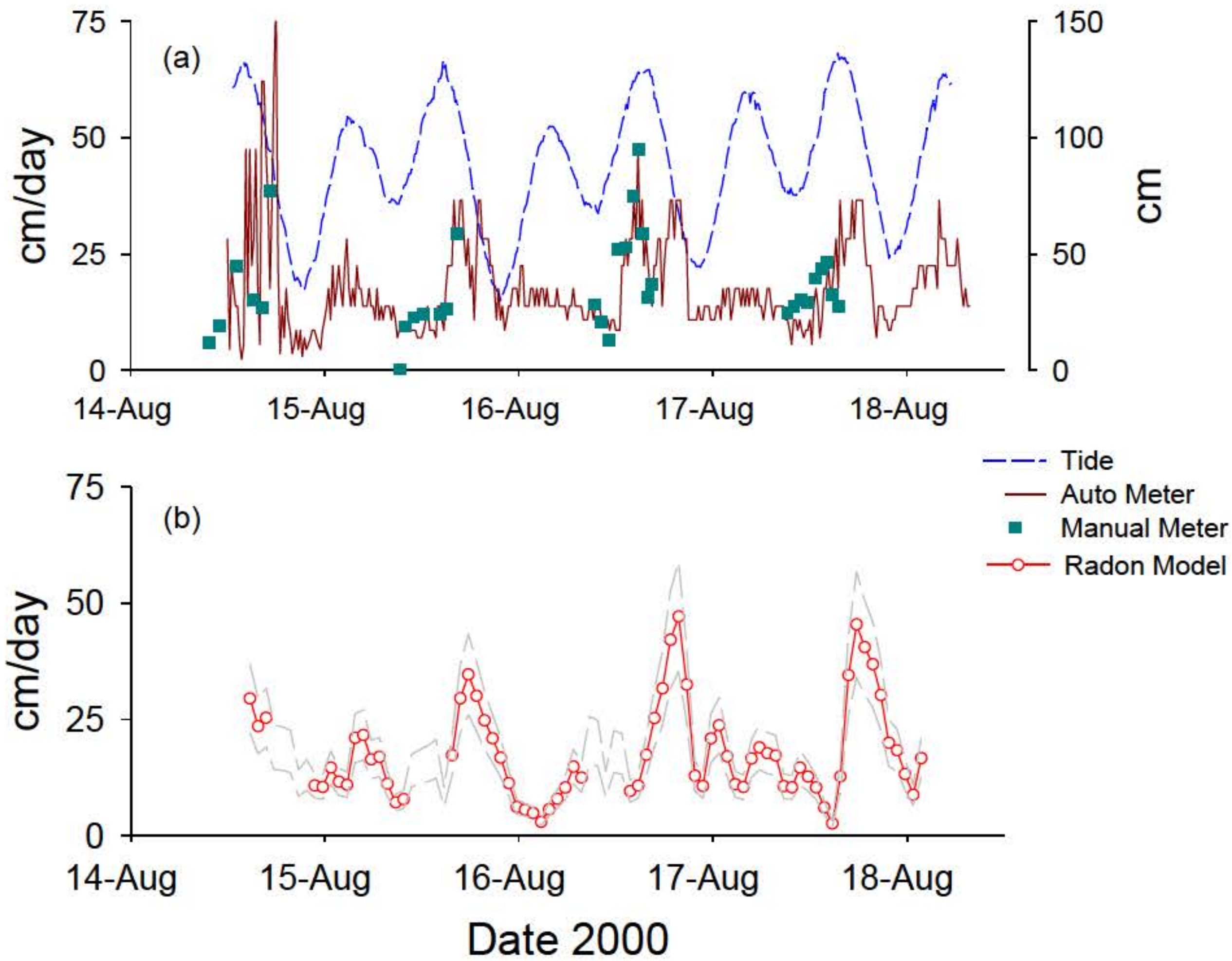

Figure 3 Records of groundwater seepage as determined by (a) seepage meter measurements; and (b) modeling the continuous radon measurements [Plot also shows tidal variation and estimated 25% uncertainty around radon-derived fluxes]

The results based on seepage meters, radon, and radium isotopic measurements compare very well, offering encouragement for these approaches. This seems especially true for the geochemical approaches in view of the relative effort involved. We feel there is still an advantage of the geochemical tracing approach as it relies on integrated water column measurements for scaling up SGD assessments to a regional level.

Reconciling the hydrological modeling results with the seepage meter and geochemical estimates will be an important aspect of our upcoming research. While differences in spatial and temporal scales make such comparisons difficult, coordination of field measurements and modeling efforts is leading to important new insights.

IMPACT/APPLICATION

The continuous radon monitor has proven to be successful for the continuous measurements of radon in low activity coastal seawater. We feel that this technique shows great promise for improving the resolution of measurements of radon as a groundwater tracer. Furthermore, the radon-in-air monitor has been successfully applied to measurements of ^{224}Ra and ^{226}Ra in natural waters. The radon and the short-lived radium isotopic approaches for evaluating SGD may prove to be most powerful when combined into the same investigation.

TRANSITIONS

Initial design and testing of our continuous radon monitor had been made through a DOD-funded joint study with Florida A&M University (Tallahassee, Florida). An aqueous radon test tank was developed and constructed during that project.

RELATED PROJECTS

This research is closely tied to the activities of a SCOR/LOICZ-funded working group on submarine groundwater discharge (http://www.jhu.edu/~scor/wg112.htm). W. Burnett is Chair of that working group which has been very active over the past few years (Burnett, 1999). We are also playing a leading role in an IOC-sponsored program to organize SGD assessment intercomparison experiments in several coastal environments. That project, "Assessment and Management Implications of Submarine Groundwater Discharge Into the Coastal Zone," was approved by the Twenty-First Session of the IOC Assembly in June, 2000 (SGD link on http://ioc.unesco.org/icam/). This 5-year program intends to: (1) develop, test, and standardize methodologies for assessment of SGD into the coastal zone; and (2) evaluate the management implications of SGD and provide appropriate training for coastal zone managers via ICAM (Integrated Coastal Area Management).

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